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OVERCOMING BARRIERS IN R&D COUPLING

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PREFACE

This paper was presented by Dr. Arthur A. Ezra as his contribution to the 1969 OAR Lectures on R&D Coupling and Information Transfer. The lectures are calculated to foster and stimulate the intellectual curiosity of Air Force R&D managers, and thus pave the way toward more rapid applications of scientific results to practical purposes.

Just as we need to spend energy on moving things from one place into another, so it seems that the speedy and successful transfer of new knowledge into practical applications cannot be achieved without a considerable investment of resources and intellectual energy. Dr. Ezra's experiences in seeking the industrial exploitation of high energy rate forming techniques vividly illustrate the validity of this proposition.

A number of Air Force people who missed the lecture asked me for copies of the talk. By publishing Dr. Ezra's narrative we wish to satisfy this demand. Moreover, we hope that the publication will provide a stimulus for a much wider discussion of this subject, and thus insure that the knowledge derived from real-life experiments in coupling can be applied to government and industrial technology transfer efforts.

I would like to express my deep appreciation to Dr. Ezra for his contribution to this field. His sponsors at the Department of Defense Advanced Research Projects Agency (ARPA), and the U. S. Army Materials and Mechanics Research Center should be congratulated for a unique and enlightened method of contracting for research which made the generation of this knowledge possible.

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ALEXANDER G. HOSHOVSKY
Information Studies Division

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1. INTRODUCTION

In 1964, the Advanced Research Projects Agency of the Department of Defense requested teams of Universities and private companies (or government research laboratories) to submit proposals suggesting ways and means of bringing about a direct coupling of science and technology.

This request for proposal struck a responsive chord in me. At the Martin Company, where I was manager of a research laboratory at the time, I had been acutely conscious of the problem of converting the results of research into technology. Many good papers for the scientific and technical journals had been coming out of the research organization, but hardly any new technology or new products.

The ARPA request for proposal gave a new perspective to what was becoming an old problem. In effect, it commanded would-be-proposers to do some fundamental thinking about the coupling of science and technology, and made it obvious that the usual cliches about the management of research would not be acceptable. It left open the choice of a research program (provided it was relevant to Materials Science) but emphasized the conversion of research results into technology.

A winning team effort composed of the Martin Company and the University of Denver chose the technical field of high energy rate forming of metals and adopted the most stringent definition of technology - an economically viable process in actual use not just a

technical report which could be used by others. This was a much more difficult task, but an infinitely more rewarding one.

The strategy for the execution of the contract was as follows. Applications leading to the establishment of new technology would be sought as spin-offs from the basic contract, getting the required support from the users who would benefit from the new technology. The basic ARPA contract money would be spent on the research that would make the applications possible. There were many good reasons for this approach. First of all, the cost of developing the application is at least ten times the cost of the research program that gave birth to it. Secondly the potential user will take a far greater interest in the application if he has a stake in it. Since the basic ARPA funded research program was directed towards anticipating and solving problems that could arise in applications, it acted as an insurance policy, and was very re-assuring to potential users of our proposed applications. What started out as a necessity, therefore, actually developed into a virtue.

II. BARRIERS TO COUPLING

The first coupling goal we set ourselves was the use of an explosively formed 10 ft. diameter dome for the Titan II Program. The Martin Company was the prime contractor of the Titan II Program, and a need has been felt for one-piece weld-free domes, which were being made of 2014 aluminum alloy. Under the stimulus of achieving this goal, we began to realize that there are natural barriers between science and technology. The process of overcoming them - the innovation process - is a complex, multi-disciplinary one,

requiring many diverse skills - marketing, selling, finance, law and even psychology.

The first step we took towards this coupling goal was initiated even before the ARPA contract was negotiated. This was the attempt to convince the potential users within the Martin Company, namely, the manufacturing division, to explosively form 10 ft. diameter domes instead of welding together a number of individual segments formed on a stretch press.

1. Manufacturing Barriers

The barriers to innovation in a manufacturing organization were observed to be the following.

a) Specifications

Specifications are intended to ensure reliability and repeatability in a manufacturing process and are a very important quality control tool. They are also a formidable barrier to innovation. A new process is expected to conform to the specifications that were developed for the old process. Everyone has forgotten how the previous specifications came into being, namely, after it had been used enough to determine its reliability, repeatability and the factors which ensured them. The new product or process can show no data on reliability or repeatability until it has been used often enough. Hence a specification for the new process cannot be written, thus making it unacceptable.

b) Costs

It is not possible to reliably estimate the cost of a new process that has never been used in production before. This makes

it difficult, if not impossible to prove the economic benefits of the new process beyond all reasonable doubt.

c) Cost Accounting Systems

Cost accounting systems are not set up with innovation in mind. Hence it is almost impossible to determine precisely the cost of an existing process which is part of a manufacturing operation. This was the case for the Titan II welded domes. Only estimates of cost could be made, and for comparison with new technology, these estimates of existing cost always tended to be on the low side. For example, the estimate of the cost of producing a welded dome that was presented at a meeting for evaluating explosive forming was a good deal lower than the estimate of cost presented at another meeting for replacing a dome on an existing pressure vessel.

d) Risks of Innovation

There is the ever present fear - well founded - that new technology will always have unanticipated technical problems, and even if technically successful, may not prove to be economically successful. In the case of failure, who in the organization will take the responsibility?

However, these apparently unsurmountable obstacles in manufacturing can all be overcome by a single expedient - call for the new process in the drawings. This relieves manufacturing, which is trained to follow drawings, from all responsibility for a potential difficulty or failure. However, it merely passes the problem from the manufacturing level to the engineering level where drawings are made.

2. Engineering Barriers

a) Configuration Control: This organizational system exercises complete control over any change that is made in a drawing once it has been approved. The system is intended to ensure the internal consistency of engineering drawings and their compatibility with manufacturing tooling and procedures. The strongest justification is required before a change can be made in an approved drawing. This built-in resistance to change constitutes an almost insuperable obstacle to innovation.

b) Schedule and Costs: A project engineer is concerned solely with meeting the required production schedule and keeping within budgeted costs. Innovation is a threat to both, and will be fought tooth and nail by a project engineer. He is well aware of the unforeseen technical difficulties that can arise with a new process, and recognizes that his goals are incompatible with those of innovation.

The only possible way to overcome the engineering barriers to innovation is to conduct a parallel development and qualification program in which the new process or product is brought to perfection before it is allowed to replace the old one.

Such a program is very costly, and therefore requires the support of non-research management at a sufficiently high level.

At this point, the crucial role of top management in the coupling of science and technology becomes evident.

3. Management Barriers

a) Reporting Level of a Research Organization

If the research organization reports at too low a level

of management, the innovation process - the coupling of science to technology - cannot be initiated. The support of top management is essential.

b) <u>High Cost of Innovation</u>

The cost of innovation is quite high - at least ten times the cost of the research program that gave birth to it and maybe more. The temptation to fund several research programs instead of one major innovation is hard to resist.

c) <u>High Risks of Innovation</u>

It is impossible to foresee all the technical difficulties that can arise and there is no guarantee of eventual technical success. There is also no guarantee of economic success, even if complete technical success is achieved. The worst hazard of all is the impossibility of accurately predicting the total cost. Decisions to continue a program have to be made every step of the way, and the further along such a program is from initiation, the more difficult each succeeding decision to continue becomes, until the end is almost in sight.

In our case, the coupling goal of explosively formed 10 ft. diameter domes for Titan, did receive support at a sufficiently high level of management. However, sufficient company funds to do the entire job could not be provided. Enough financial support was given so that the feasibility of explosively formed domes could be established. On the basis of this data, the Air Force funded an improvement program which paid for the cost of a parallel development and qualification program.

While this program was carried through to a successful conclusion, enough difficulties arose to reveal the existence of additional natural barriers in the development process.

4. Development Barriers

a) Training and Technology Transfer: When the development stage is initiated, the control passes from the research people to the project people. Unfortunately, the required depth of technical knowledge is not passed on to the project people. This has serious consequences when unanticipated technical troubles begin to appear, as they must, in this stage of development. The traditional project engineer is attuned to costs and schedules, and if at any point in time it appears that anticipated costs and schedules will be overrun, he will unhesitatingly recommend cancellation of the project on the grounds that it was premature, thus shifting the onus of failure from his own shoulders.

A different approach must be used to overcome this barrier. The development program must be preceded by a careful training program conducted by the research people. The proposed project engineer and other key technical people on the project should be trained and qualified before they are given the responsibility of the development program. Traditional attitudes of project management have to be changed. The existence of unforeseen technical difficulties must be accepted and budgets for contingencies must be provided. The research responsibility which is reduced to an advisory role, must still retain a veto power over technical decisions.

b) Procurement Barriers

A new process or product may require materials or components that are not readily available, or impossible to get. Substitutions must never be accepted until their full consequences can be evaluated. This often cannot be readily done because there is not enough depth of knowledge behind the new process. Every procurement compromise must be regarded as a potential difficulty, and it is often better not to proceed with the new program until it is resolved.

c) Survival Barriers

A particular application that has been chosen for a development program may prove to have only marginal economic benefits or none at all. Since it is always cheaper and faster when something is done for the second time, due weight must be given to the effect of learning and experience on future costs. Since this is hard to quantify, it is wise to immediately seek other applications close to the original one so that the effects of experience on cost can be demonstrated in a timely manner. This was our experience on the explosively formed Titan II 10 ft. diameter dome. The benefits were marginal, but immediate subsequent application of this knowledge to explosively form 5 ft. diameter domes for another missile program in the Martin Company proved to be better and cheaper than spinning. This enabled explosive forming to gain a more durable foothold in the Manufacturing Division, where it is now accepted as a forming process.

Since all applications cannot be uniformly successful, a

new technology must keep expanding in order to survive. In order to expand, it needs a steadily increasing number of trained personnel. A University plays a key role here, since one of its major functions is teaching. The basic knowledge of the new process has to be imparted to students, who can then be assimilated into the expanding technology.

III. MANAGEMENT PROBLEMS & RECOMMENDATIONS

1. Timing: It is always difficult to determine the appropriate moment to begin the coupling process, i.e., to begin trying to apply the results of research. If the effort is made too soon, problems will certainly arise and there is the fear that the emerging new technology will be dubbed a failure.

Experience has shown that unanticipated problems will always arise, no matter what the timing. Management just has to adjust itself to this, if it wishes to make a serious effort to couple science and technology. In a research environment it is impossible to foresee every technical difficulty that will arise when applications are attempted. The coupling program just has to provide for unanticipated difficulties, and must be prepared to send the program back to research if necessary. This does not consitute failure, since the technical problems of converting research results have to be identified before they can be solved. Not only will this attempt at applications identify the problems but will give a new perspective and fresh outlook to the research program itself which it would never have acquired otherwise. It will also provide a useful training process for those who will ultimately have the responsibility for the final development program.

A formal effort must be made, however, to transfer all the knowledge that is possible from research to the project people before the coupling effort begins. This will ensure that a learning experience and not a traumatic experience will occur. This transfer of knowledge will not be easy. Research people will have to divert their efforts to teaching, incomplete scientific knowledge will have to be put in a form that can be assimilated by people with a lesser depth of knowledge. Unless there is complete acceptance of this plan of action by the people involved, and a thorough understanding of its reasons, there will be strong resistance every step of the way.

In the last analysis, the attempt to couple will provide valuable data for a management decision to either give wholehearted support or to weed out a particular research program. The sooner such a decision is made the better.

2. Selection: A research director will be faced by a bewildering variety of choices when he tries to select a research program to initiate the coupling process. Nobody can possibly have the required depth of knowledge in all the various disciplines respresented by the research programs. How, then, is it possible to choose wisely? First of all, he must accept the fact that no matter which program he chooses, troubles will develop, and that the purpose of making this selection is to identify the difficulties. It therefore makes no difference which program he selects since these objectives will be met by any one of them. The only difference is that some will run into troubles sooner than others. If the coupling program is designed with the

necessity of a strategic withdrawal in mind, it can safely be predicted that every coupling program will go according to plan.

Every year at least one research program should be singled out for special attention to initiate the coupling process. This will help to identify those research people who are latent entrepreneurs and whose research programs will consequently have a higher probability of success.

It would be wise for an advisory or review committee to help select the research program. This not only provides the benefit of different points of view, but also shares the responsibility for the risk inherent in such a program.

3. <u>Organization of a Coupling Program</u>: Experience on the ARPA coupling program shows that a three way team effort, with government, industry and university participation is both logical and fruitful. Because of the high risk and the large amounts of money involved, the government is involved by necessity, as it has been in the past, in all new technological developments of any significance. In this case however, the government contract monitor must be a well qualified technical man, as the role he must play goes well beyond the conventional bookkeeping one. He has to participate actively, by helping to identify potential applications for the research results within the government; he must arbitrate disputes between the industry and university team members; and he must take responsibility for the unpleasant but necessary task of pruning and trimming the program as it proceeds.

The University role in such a program is to provide the necessary depth and breadth of scientific and technical knowledge, and to generate the supply of trained engineering students who will be needed for the new technology to survive and grow. The University role in systematizing and disseminating the new knowledge is essential. A coupling program must therefore provide for this information dissemination and educational task in addition to the research efforts.

The role of the industrial organization is obvious - it is the user of the new technology.

IV. CONCLUSIONS

The principles of coupling that have been generated by this ARPA program need to be put to the test. Only after a specific test case will there be enough confidence to encourage their widespread use by research management.

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13. ABSTRACT

The purpose of this paper is to share the lessons learned from a real-life effort of seeking practical applications of new technology resulting from research efforts under an ARPA contract. The paper identifies numerous obstacles that must be overcome by a proponent of a technological application; the manufacturing barriers of specifications costs, cost accounting systems and risks in innovation; the engineering barriers of configuration control, schedule and costs; the management barriers of risks and costs, development barriers of training and technology transfer, procurement and survival. The impact of these barriers is that the innovation process is a complex, multidisciplinary one, requiring many diverse skills - marketing, selling, finance, law and even psychology. The author points out certain implications for R&D management; the need for proper timing of the coupling process, the proper selection of the technology to be coupled, the need for the organization of the coupling programs, and a need for testing of some ~~of his~~ hypotheses.

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